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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Datasets of odontocete sounds annotated for developing automatic detection methods

by

David K. Mellinger

September 2007

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Prepared for: CNO/N45, Washington, D.C.

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13. ABSTRACT ***(maximum 200 words)***

Environmental laws and public concern require that the U.S. Navy conduct operations and training such that impacts to marine mammals are minimized and any adverse impacts mitigated. To that end, it is important for the Navy to monitor the occurrence and behavior of marine mammals during research and operational activities. One method for this is passive acoustic monitoring, which has primarily been used for baleen whale vocalizations. However, baleen whales are only a small fraction of marine mammals, whereas the greatest public concern and possible impact to Navy operations now centers on odontocetes, particularly beaked whales. Accordingly, passive acoustic monitoring techniques need to be extended to odontocetes. This report documents the compilation of an archive of existing beaked whale recordings, and summarizes the deliberations/discussions at a meeting in Boston (Sept. 2006) to determine (or, at least, reach consensus of) how the content, structure, and format of that archive should look. The archive, which will then be usable for studying automatic recognition of marine mammal (particularly odontocete) sounds (i.e., passive acoustic monitoring), is presently available to researchers and engineers through the MobySound database at Oregon State University.

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Datasets of odontocete sounds annotated for developing automatic detection methods

Final report

submitted pursuant to award number N00244-06-P-1870

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Project Overview

The basic aims of this project are to collect recordings of beaked whales, annotate them to make them useful to researchers working on automatic call detection and classification, and make them available on the Internet. In more detail, the tasks and their milestones were as follows:

(A) Survey marine mammal scientists to find what recordings of beaked whales exist.
Milestone: A spreadsheet listing the available recordings, by species.

(B) Convene a meeting to discuss the content, structure, and format of the data and annotations in the archive. This meeting will be kept small, to roughly 10 people. Personnel will come principally from institutions that conduct marine mammal acoustics research, such as Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, Cornell University, Aarhus University, University of Hawaii, etc.
Milestone: Meeting held.

(C) Create the archive shell, the structure (including web access) into which the archive will be placed.
Milestone: A working, accessible web site for retrieving recordings.

(D) Collect available beaked whale recordings.
Milestone: Have recordings in digitized form on hand at OSU.

(E) Annotate these recordings and enter them into the archive.
Milestone: Annotations available together with on-line recordings.

(F) Have the archive "go public" so that it becomes available to researchers in detection methods.
Milestone: Public access to web site with beaked whale sounds and annotations.

(G) Continue collecting and annotating other odontocete recordings as possible and adding them to the archive.
Milestone: Recordings on hand and annotated as resources are available.

Results

The results by task are as follows:

(A) [Survey to find recordings] This was performed in Jul.-Sep. 2006. The table of extant recordings of beaked whales is included in Appendix 1.

(B) [Convene a meeting] This meeting occurred in Boston in Sep. 2006 in conjunction with the IEEE Oceans '06 conference. Eleven people attended. A summary of the meeting is included as Appendix 1.

(C) [Create archive shell] This was done in Oct.-Nov. 2006. The archive may be seen at http://hmsc.oregonstate.edu/projects/MobySound/.

(D) [Collect available recordings] This was done. Some of the extant recordings could not be collected, either because their owners considered them proprietary, or (for older recordings) their owners could not locate the tapes. The list of collected recordings is shown in Appendix 2.

(E) [Annotate the recordings] This was done for the recordings listed in Appendix 2. Annotating beaked whale recordings was found to be surprisingly arduous, partly because it was difficult to distinguish beaked whale clicks from other, similar sounds. The criteria for distinguishing beaked whales from other sounds were given by Moretti et al. (2006) and Johnson et al. (2004, 2006); the main ones were rapid roll-off in the spectrum below about 25 kHz, and the upsweeping nature of the recording.

(F) [Have the archive "go public"] This was done via a journal article, which covered the mysticete sounds in the archive (Mellinger and Clark 2006), and via a presentation at the Third International Conference on the Detection and Classification of Marine Mammals using Passive Acoustics, (Boston, 2007), which covered the beaked whale sounds and other odontocete sounds (Mellinger et al. 2007). The abstract of the article is included as Appendix 3, and the abstract for the presentation is included as Appendix 4.

(G) [Continue collecting, annotating, and posting recordings] This work continued through the end of June 2007, and is continuing now via a follow-up grant (#N00244-07-1-0005) to do similar collection, annotation, and web-posting.

Acknowledgements

Thanks to all the contributors of recordings shown in Appendix 2. Thanks also to Dave Moretti and Nancy DiMarzio for invaluable help in teaching us how to distinguish a beaked whale sound from other similar clicks.

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Moretti, D., N. DiMarzio, R. Morrissey, J. Ward, and S. Jarvis. 2006. Estimating the density of Blainville's beaked whale (*Mesoplodon densirostris*) in the Tongue of the Ocean (TOTO) using passive acoustics. Proc. IEEE Oceans '06, 5 pp.

Appendix 1:
Summary of the meeting to discuss a beaked whale sound archive.

Meeting notes: Odontocete Sound Datasets for Automatic Detection and Localization
New England Aquarium's Ocean Center Dave Mellinger

Sept. 21, 2006

Francine Desharnais, Nancy DiMarzio, Sara Heimlich, Franz-Peter Lam, Mark McDonald, David Mellinger, Dave Moretti, Ron Morrissey, Sharon Nieukirk, Peter Tyack, Ildar Urazghildiiev.

This is a summary of a meeting in Boston organized by Dave Mellinger. This meeting was held to reach a consensus on how to collect and annotate data to use for research on automatic detection of odontocete sounds, particularly beaked whale sounds. In part, the aim was to decide on dataset(s) for the next workshop on detection and localization, which will be held in summer 2007 (most likely around July 25) in Boston, and which will focus on detection of beaked whales. (Below, this is called the "next workshop".) But the larger question is what information will be most useful for researchers working on the odontocete detection and classification in general.

There are many levels at which automatic detection might operate:

- detect a given taxon for mitigation of a certain disturbance (e.g., beaked whales and midfrequency sonar; right whales and ships)
- detect all marine mammals (or all cetaceans) for mitigation (e.g., seismic surveys)
- detect presence/absence of a species for a range/distribution survey
- detect/count all individuals (or all calls) to estimate the population
- detect all sounds of a species for use in behavioral/social study
- or all sounds of a certain type, e.g., codas of sperm whales

We would like datasets that address as many of these issues as possible, with a manageable amount of work to prepare the datasets.

This summary follows the order of the meeting agenda. *Italic* items are from the agenda.

Recordings: What recordings are available?

We covered this species by species:

Cuvier's beaked whale (*Ziphius cavirostris*)

Manghi et al. 1999	Ionian Sea	modulated whistles, upsweeps
Frantzis et al., 2002	Mediterranean	click sequences
Johnson et al. 2004, Zimmer et al. 2005, Aguilar de Soto et al. 2006	Ligurian Sea	DTAGs on the animals; these are all the same recordings; how much total BW DTAG data have Tyack, Johnson, et al. collected?
D. Moretti et al.	Bahamas	many AUTEC recordings, none verified
J. Hildebrand	S. California (SCORE)	not sure about visual confirmation

J. Hildebrand	Sea of Cortez	dipping phone, visual confirmation w/flat
J. Burtenshaw		seas
P. Perkins (1973)	Captive	tapes are at Cornell ML; "same cruise as Winn 1970" (?)

Mark McDonald has access to recordings from Cobb Seamount:

- species is unknown: Ziphius and Mesoplodon were present
- < 1% of presumed beaked whale clicks occurred in daylight, 99% at night
- 4 kinds of click (swept) w/ no correlation; don't see known Ziphius sweeps

Blainville's beaked whale (*Mesoplodon densirostris*)

Caldwell & Caldwell 1971	Florida	1-6 kHz; recordings still available?
Johnson et al. 2004; Madsen et al. 2005	Canary Is.	DTAGs on the animals
D. Moretti et al.	Bahamas	many AUTEC recordings, many of them visually confirmed
S. Martin/ D. Moretti	Kauai (PMRF?)	monitored the area for NPAL; no visual confirmation
S. Martin/ D. Moretti	Kauai PMRF	recent; no visual confirmation

Hubbs' beaked whale (*Mesoplodon carlhubbsi*)

Lynn and Reiss 1992	California (captive)	two click types: low-frequency (peak freq 2 kHz) and broadband (7-35 kHz)
Marten 2000	?	recording of unknown quality

Northern bottlenose whale (*Hyperoodon ampullatus*)

Winn et al. 1970	Atlantic (Nova Scotia?)	two click types; possibly whistles; might be pilot whales (?)
Hooker and Whitehead 2002	Nova Scotia	two click types, separable by frequency and ICI
Fauchner and Whitehead	Nova Scotia	recording to 35 kHz

Baird's beaked whale (*Berardius bairdii*)

Dawson et al. 1998	Oregon coast, Baja	whistles; 2 click types (peaks at 23 and 38 kHz)
M. McDonald (1996)	US Pacific coast	2 sonobouys, visually verified, 20-25 animals

Hector's beaked whale (*Mesoplodon hectorii*)

M. McDonald	Drake Passage	sonobuoys, visually verified, Beaufort 0 conditions

Arnoux's beaked whale (*Berardius arnuxii*)

Hobson and Martin 1996	Antarctica	any more information about these?
Rogers and Brown 1999	Kemp Land, Antarctica	pulsed tones and whistles; clicks

Ambiguous: Southern bottlenose whale (*Hyperoodon planifrons*) or Arnoux's beaked whale (*Berardius arnuxii*)

Leaper and Scheidat 1998	Southern Ocean	click sequences
Leaper et al. 2000	Southern Ocean	rapid click trains; same data as Leaper et al. 1998?

Other:

Recordings reliably identified as bottlenose dolphins (*Tursiops truncatus*), sometimes identified to the level of individual animals, are available from researchers studying the Sarasota Bay population.

Sperm and right whale datasets from the previous two workshops on detection and localization are available as well.

Certainty of Species ID: How do we handle differing levels of certainty about species identity in the sound datasets?

Everyone present agreed that for nearly all beaked whale species, there simply aren't enough sound recordings with positive visual confirmation of the species identity, and that research on call recognition would have to proceed using recordings with lower levels of certainty. Everyone also indicated that the certainty level was an essential component of the metadata, but no one was sure how to quantify it; for instance, giving a numeric score would be difficult. Certainty could be from many sources (visual confirmation of the species, high number of very stereotypical pulses that had been confirmed in the past, etc.) and we should state the source of certainty. The consensus seemed to be a qualitative measure: none, low, medium, high. It was also suggested that sound datasets with a certainty level below "high" should have the certainty level indicated in some very obvious way, such as making it part of the dataset name, so that researchers would be reminded often about this uncertainty.

Annotation of Recordings: What to mark: Individual clicks? Click sequences? Whistles too? What about multiple animals with overlapping whistles and click sequences? Annotation details depend on the problem that a detection algorithm aims to solve; how can we annotate recordings most generally to handle as many detection problems as possible?

Annotation of sound recordings for research on automatic detection of baleen whales has typically involved delineating the time/frequency bounds of each call. Should a similar thing be done for odontocete clicks – that is, delineate every one in at least time, and perhaps also frequency? What about whistles? What data should we include? A significant issue is knowing the "right answer" for making annotations. That is, how do we know for certain when a click or whistle is present or absent, given that they may be any level above or below background noise? Sometimes detectors, such as matched filters, detect sounds that are invisible in spectrograms; belief that such detections are correct may be based on cues not used by the detection process, such as inter-click intervals, being in an expected range.

There was a consensus here that annotation should be based on the best known evidence, and that corrections to annotations should be possible. That is, the initial annotation for a given recording should be based on the best methods that annotators have available, be this spectrogram examination, a matched filter, another detection method, etc. If other researchers present convincing evidence that previously unknown calls are present, then the annotations will be updated to reflect this information. (But the older versions of the annotations should be preserved – see below about a versioning system.)

Clicks vs. Whistles: How are data needs different?

Recordings from social groups often contain overlapping whistles from two or more individuals, making annotation particularly difficult. Clicks can overlap too, of course, but because each click is so short, it's less likely to overlap other clicks.

Whistles were thought more likely to vary from one individual to another, and perhaps from one group or population to another. This necessitates larger datasets for robust detection.

Whistles also fade into background noise in both time (i.e., at the start or end) and frequency (e.g., higher harmonics), making it difficult to delineate T/F boundaries.

As described below, the initial effort will be for clicks only. However, it was also agreed that for some species it may not be possible to get data with clicks alone, as whistles are an integral part of the vocal repertoire of some species, and that whistles may be essential for species identification.

Metadata: What metadata will be most useful for detection and classification? Localization?

We came up with a list of useful metadata for detection, classification, and localization. This is the information that should be supplied about each recording. In some cases (e.g., distance from animals, signal-to-noise ratio, behavior) the information will change over the duration of the recording, or even from vocalization to vocalization:

recordist (person)
recording equipment, frequency response, sample rate, bit depth
time/date of recordings; is that part of the sound files?
geographic area/location (lat and long)
position and speed of hydrophones (x, y, z); may be a track (e.g., GPS track) for mobile hydrophones
time and frequency of vocalizations (or presence/absence of them within specific time spans)
signal-to-noise ratio
species and numbers of individuals present – degree and type of verification
behavior
on-axis / off-axis / unknown
sound speed profile
bottom depth at sensor (or bathymetry of the area)
bottom characteristics
sea state / swell size
references to published literature that concerns the recording
sources of noise and interfering sounds
distance from recorded animals
T/F positions and types of vocalizations of interest
date of modification of metadata

It was agreed that we should find out what Cornell's Macaulay Library does, since they have extensive experience with metadata issues.

Storage: What is the best way to make data sets (sound + metadata) available on the web?

The principal issues here are

- longevity: the data should outlast any single researcher's career
- reliability: data should be backed up frequently, with off-site storage
- modifiability: metadata describing vocalizations within recordings may need correcting
- packaging: in each dataset, sounds and metadata should be grouped so that they may be

downloaded as a single unit

- accessibility: a very-high-speed net connection is needed for high-frequency data

To handle modifiability, version numbering might work. Each time metadata is changed (corrected or updated), a version number is incremented. This allows dataset users to (1) easily determine the most recent, and hopefully best, version; (2) determine when a previous version they downloaded has been modified; and (3) download an older version for comparison of old results with new (provided old dataset versions are retained).

Initially, OSU could host the archived data as part of the MobySound database. As a more permanent solution, the Macaulay Library (ML) was mentioned as a possible archive site. However, meeting participants noted that ML charges some users for its sounds, which may make this dataset less accessible to users with limited budgets. The waiver of ML charges for academic/research use might make this a non-issue, but there was still concern with ML. Also, it is unclear whether ML supports version numbering and packaging groups of recordings together. Participants also suggested some sort of commercial hosting or contacting Scripps regarding their web-accessible oceanographic database.

<u>Data Quantity</u>: How many click datasets do we need? Whistle datasets? How much data in each one? If beaked whales are our initial aim, what other odontocete sounds do we need?

We talked about a "multi-tier" arrangement for the datasets, with Tier I data being recordings for the next workshop, Tier II data being a significantly larger set of recordings for beaked whale detection, and Tiers III and later including data targeted at detection of other odontocetes to be determined.

For Tier I data, Dave Moretti and Bob Gisiner had agreed, earlier this summer, on requirements for the next workshop's dataset. Bob emphasized the importance of keeping the dataset simple, to make it possible to make it available quickly, and strongly suggested that it include only click sounds at present. Very little annotation of these recordings will be needed. The following is excerpted from Dave's document:

> The analysis data will consist of both training and test data. Training data sets will consist of a minimum of 5 cuts for each of the following species:
>
> 1. *Mesoplodon densirostris* (Blainville's beaked whale)
> 2. *Steno bredanensis* (rough-toothed dolphin)
> 3. *Stenella attenuata* (pantropical spotted dolphin)
> 4. *Globicephala macrorhynchus* (short-finned pilot whale)
>
> Each cut will contain a minimum of 100 clicks, along with whistles if present. The data will be presented as a continuous cut of at least 2 minutes in length and will give the researcher the opportunity to view vocalizations in context. Such measures as interclick interval can be obtained if desired.

Five test data sets containing the following signals will be produced:

1. No signals of interest (sperm whale vocalizations)
2. High-SNR signal sets for the 4 species of interest (note: some are likely to contain multiple individuals)
3. A mixed-species cut
4. A low-SNR data set for the 4 species of interest
5. A multi-individual beaked whale set

Each cut will be a minimum 10 minutes in length. Each cut will be provided as an individual wave file. [Mellinger's lab will make the dataset available on the web via the MobySound archive.]

For Tier II, the aim will be to gather as many as possible of the beaked whale recordings listed above. Annotation will initially focus on click sounds, and will principally consist of taking long recordings and, for selected short segments of them (1-10 minutes), indicating what species are present, if any. Some segments will not include any identifiable sounds from marine mammals at all. Some may include whistles, and these may be annotated as such, with species identity if known.

There was a consensus that annotating individual clicks was not a requirement for these datasets.

Requirements for Tier III will be defined at a later date.

As to the number of recordings, clicks, click sequences, or whistles needed, we didn't reach any consensus. Mellinger said his rule of thumb for baleen whale sounds was to have at least 500 examples of each vocalization type, as well as 500 other sounds as examples of what not to detect. This number is suitable for, say, training neural networks. It was unclear what approximate numbers are needed for clicks and for whistles. The way to proceed here seems to be to make some datasets available, let researchers use them for training and testing, and determine which need supplementing and by how much.

It was agreed that robust detection algorithms need data gathered in a variety of different recording situations, since these situations will have different noise sources and noise levels, different environmental conditions, different acoustic propagation, etc.

Appendix 2:
Status summary of the recordings currently in the archive.

Data In Collection/Library:

Beaked Whales.

- Blainville's Beaked Whale (*Mesoplodon densirostris*)
  - AUTEC (NUWC & WHOI): 41 files, 67613s total
  - Canary Is. (Johnson):1 file; 1260s total
  - ETP (Rankin): 3 files; 19.7s total
- Baird's Beaked Whale (Berardius bairdii)
  - Alaska (Rankin): 7 files; 646.5s.
  - Aleutian Islands (Stafford): 13 files; 6588s total
  - Baja (Dawson & Barlow): 60 files of undetermined time (requires conversion from Canary format)
  - Oregon (Ljungblad & Barlow): 1 file; 19.4s total
- Cuvier's Beaked Whale (Ziphius cavirostris)
  - Italy (Johnson): 1 file, 1800s total
- Unverified beaked whales mixed with other odontocetes
  - Oregon and California (McDonald): 11 files; 354.6s total
  - AUTEC (NUWC & WHOI): 39 files, 70200s total

Risso's Dolphins (*Grampus griseus*)

- AUTEC (NUWC): 10 files; 17100s total

Rough-toothed Dolphins (*Steno bredanensis*)

- AUTEC (NUWC): 2 files; 3600s total

Pantropical Spotted Dolphins (*Stenella attenuata*)

- AUTEC (NUWC): 1 file, 1800s total

Long-finned Pilot Whales (*Globicephala macrorhynchus*)

- AUTEC (NUWC): 9 files; 13500s total

Sperm Whales (*Physeter macrocephalus*)

- AUTEC (NUWC): 3 files; 2790s total

Data Measured:

Cuvier's, Italy (Johnson): 1 file, 1800s	3137 total calls annotated
Blainville's Canary Is. (Johnson): 1 file, 1260s	3000 total calls annotated
Blainville's AUTEC (NUWC): 1 file, 1080s	1596 total calls annotated
Blainville's AUTEC (WHOI): 2 files; 3600s	2041 total calls annotated

9776 total annotated beaked whale clicks

Appendix 3:
Abstract of a peer-reviewed journal article on the structure and preliminary contents of the archive.

The reference for this article is

Mellinger, D.K., and C.W. Clark. 2006. MobySound: A reference archive for studying automatic recognition of marine mammal sounds. Appl. Acoust. 67:1226-1242.

Abstract:

A reference archive has been constructed to facilitate research on automatic recognition of marine mammal sounds. The archive enables researchers to have access to recorded sounds from a variety of marine species, sounds that can be very difficult to obtain in the field. The archive also lets researchers use different soundrecognition methods on a common set of sounds, making it possible to compare directly the effectiveness of the different methods. In recognizing sounds in a given recording, the type and frequency of noise present has a strong effect on the difficulty of the recognition problem; a measure of the amount of interference was devised, the "time-local, in-band, signal-to-noise ratio", and was applied to each sound in the archive. Current entries in the archive comprise lowfrequency sounds of large whales, and have about 14,000 vocalizations from eight species of baleen whales. MobySound may be accessed at http://hmsc.oregonstate.edu/projects/MobySound/. Contributions to the archive are welcomed.

Appendix 4:
Abstract of the presentation given about this project at the Third International Conference on the Detection and Classification of Marine Mammals using Passive Acoustics, Boston, 2007.

An annotated archive for detection of toothed cetacean sounds: MobySound for odontocetes

David K. Mellinger (1), Sara L. Heimlich (1), Sharon L. Nieukirk (1), David J. Moretti (2), Nancy A. DiMarzio (2)

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Progress in automatic detection of marine mammal sounds can be enhanced by the availability of datasets of annotated recordings. With datasets openly available and widely used, different researchers can train and test their methods using the same data, allowing meaningful comparison between methods. Annotation is used to indicate where (in time and frequency) within long recordings the sounds of interest occur. It can also indicate the signal-to-noise ratio of the target sounds, so that performance can be characterized by signal-to-noise ratio (SNR) -- an essential factor in evaluating any detection method. The MobySound archive [Mellinger and Clark, Applied Acoustics 2006] has to date consisted primarily of baleen whale vocalizations, but now it includes sounds of odontocetes. Odontocete sounds present unique challenges for such an archive. These sounds, particularly clicks, are not as distinctive as most stereotypical baleen whale calls, making accurate visual identification of the sound source of paramount importance. Recordings must be made at a high sampling rate to capture the high frequencies of the sounds, leading to sound files of very large size. Characterizing SNR for extremely short sounds, such as odontocete clicks, requires a different technique than that used for the much longer baleen whale sounds: SNR is measured by filtering the recording to retain only the frequency band of interest, then measuring the peak-to-peak click level in the time series. To date, MobySound contains several thousand annotated clicks of Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), long-finned pilot whale (*Globicephala macrorhynchus*), and Risso's dolphin (*Grampus griseus*). More species are anticipated.

Initial Distribution List

1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, VA 22060-6218	2
2.	Dudley Knox Library, Code 013 Naval Postgraduate School Monterey, CA 93943-5100	2
3.	Erin Oleson Scripps Institution of Oceanography University of California La Jolla, CA	1
4.	John Hildebrand Scripps Institution of Oceanography University of California La Jolla, CA	1
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6.	Greg Schorr Cascadia Research Collective Olympia, WA	1
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20.	Kate Stafford Applied Physics Laboratory University of Washington Seattle, CA	1
21.	Sue Moore NOAA at Applied Physics Laboratory University of Washington Seattle, WA	1

22.	Andrew Read Duke University Marine Laboratory Beaufort, NC	1
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